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GENESIS OF THE ADIRONDACK MAGNETITES.

HAROLD L. ALLING.

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CONTENTS.

INTRODUCTION.

The reader may well inquire the reason for the appearance of another paper on the Adirondack magnetite deposits in view of the contributions of Kemp, Newland, Miller and Nason,[2] but those who have followed the recent discussions regarding the

[1] Published with the permission of the Director of the New York State Museum, Albany, N. Y.

[2] Kemp, J. F., "The Geology of the Magnetites near Port Henry, N. Y. and especially those of Mineville." *Trans. Am. Inst. Min. Eng.*, vol. XXVII., pp. 147–203, 1897 (1898).

Kemp, J. F., *N. Y. State Mus. Bull.* 119, pp. 57–88, 1908; 138, pp. 97–149 1910.

Newland, D. H., *N. Y. State Mus. Bull.* 119, 1908; ECON. GEOL., vol XV., pp. 177–180, 1920; ECON. GEOL., vol. XVIII., pp. 291–296, 1923.

Miller, W. J., "Magnetite Iron Ores of Clinton Co., N. Y.," ECON. GEOL., vol. XIV., pp. 509–535, 1919. "Origin of Adirondack Magnetite Deposits," *Bull. Geol. Soc. Am.*, vol. XXXII., pp. 63–64, 1921. ECON. GEOL., vol. XVI., pp. 226–233.

Nason, F. L., "The Sedimentary Phases of the Adirondack Magnetite Iron Ores," ECON. GEOL., vol. XVII., pp. 633–654, 1922; ECON. GEOL., vol. XIX., pp. 288–295, 1924.

genesis of these important ore bodies in Northern New York may reach the conclusion that there is a hopeless disagreement among those who have studied these deposits. It is because I feel that much of this disagreement is more apparent than real when the literature is summarized and further petrographic studies undertaken that this paper is here offered.

Acknowledgments.—I am greatly indebted to Professor Kemp and to Mr. Newland for aid in understanding the field relations of these deposits. They have freely discussed with me the subject of origin. I also wish to thank Professor R. J. Colony for the exchange of views regarding the magnetite deposits in Southeastern New York, and the comparison of those ore bodies with those in the Adirondacks. I am under obligations to Frederick W. Apgar who has kindly furnished a manuscript report on the petrography of the iron ores of the Champlain district.

THE COUNTRY ROCK.

In former years geologists called the country rocks gneisses, as they are, but found it exceedingly difficult to reach any definite conclusion as to whether they were igneous or sedimentary. They realized that they were distinctly banded and that the foliation was roughly parallel to the ore bodies themselves, thus, one may understand why some observers regard them as ancient sediments. But with the minute examination of the country rock with the microscope and Cushing's recognition of the syenite series, we now realize that they are in major part of igneous origin. I say " in major part " igneous for there is very definite evidence that they are not pure simple igneous rocks, but in many cases they are of composite nature.

The mineralogy of these country rocks varies somewhat from place to place, but they are essentially low quartz-bearing soda syenites to soda granites. The different Adirondack geologists, however, might use a local or special term for this important rock. It is the Lyon Mountain granite of Miller, it is the syenite-granite series of Cushing, it is the soda granite, and the ore-formation granite of my nomenclature. In all cases it is essentially

the same rock under different names. The striking features of the rock consists of the relation of the feldspars to each other, the high magnetite content in certain localities, and the soda bearing character of the pyroxene. The characteristic feldspar is a perthite—an intergrowth of soda rich and potash rich feldspars. In most of the rock there is a higher percentage of the soda rich phase. Oftentimes in addition to perthite, microcline and oligoclase appear. Locally the perthite entirely fails and the two last mentioned feldspars take its place. From a careful study of this rock and its feldspathic content, it is clear that there is no marked difference in composition between the perthitic type and the microcline-oligoclase type. It is because the microscopic examination reveals such striking differences that these rocks are called by different names, accounting for some of the apparent confusion.

The wall rocks of the Adirondack magnetite deposits have been compared with those of Sweden by Newland:[3] "At Gellivare . . . no sedimentary gneisses are recognized in the vicinity. The general impression gained . . . indicates close resemblance to the ore-bearing syenitic gneisses in the northern Adirondacks, particularly Lyon Mountain, Palmer Hill and Arnold. . . . Mineralogically and chemically the two series are very similar. Both are characterized by high soda percentages, which place them in the soda-syenite class, the prevalence of perthitic and acid plagioclase feldspars, and by relatively large amounts of . . . magnetite, which has, however, a very unequal distribution due to its tendency to aggregate in bands and schlieren surrounded by rock containing less than the average proportion of magnetite." Speaking of the wall rock of Palmer Hill, Newland[4] adds that "In its mineral and chemical properties the rock belongs to the general type of soda-rich granites and syenite that have come to be known as the predominant magnetite-bearing rocks the world over." Miller[5] apparently disagrees with New-

[3] Newland, D. H., "Notes on the Geology of the Swedish Magnetites," *N. Y. State Mus. Bull.* 149, 1911, p. 110.

[4] Newland, D. H., Econ. Geol., vol. XV., p. 180, 1920.

[5] Miller, W. J., Econ. Geol., vol. XVI., 1921, p. 232.

land about the soda-rich character of the wall rock, when he says: "Nor is such granite especially soda-rich as Newland claims, certainly not more so than the ordinary syenite and granite of the Adirondacks in general." It is true that they are not astonishingly high in soda but they are soda-rich when compared with the usual run of granites from other localities. Their soda rich character led Cushing [6] to compare them with the Norwegian akerites. "While some of our rocks could be referred to as such, the majority of them are more akin to the nordmarkite series." [7] Kemp and I have classified the syenite-granite series as ranging from laurvikites, through nordmarkites, quartz nordmarkites, to soda granites. I feel that there is not as much difference between Newland and Miller as the latter's papers would indicate.

Leith's editorial on "field *vs.* laboratory evidences in the identification of metamorphic rocks" [8] and the discussion of Miller [9] Nason [10] and Newland [11] relative to the nature of the country rocks of these magnetite deposits call our attention to the problem of their origin. Leith is unquestionably correct in laying stress upon field evidence as opposed to laboratory work. However, I seriously doubt the correctness of his advocacy of the sedimentary origin of the country rock of the Mineville district. He is, as he himself says, influenced by his extensive experience in the Lake Superior region. Perhaps the difficulty arises more from our insistence that a rock must be either igneous or sedimentary rather than in the actual rocks themselves. An excellent illustration is the comparison of two papers by Kemp [12] covering an interval of ten years. The early paper, to which reference is seldom made, presents in many respects a more satis-

[6] Cushing, H. P., "Augite-syenite Gneiss near Loon Lake, N. Y.," *Bull. Geol. Soc. Am.*, vol. X., pp. 177–192, 1899.

[7] Kemp, J. F., and Alling, H. L., "The Geology of the Ausable Quadrangle," *N. Y. State Mus. Bull.* (in press 1924. Mss., p. 54).

[8] Leith, C. K., Econ. Geol., vol. XVIII., pp. 288–290, 1923.

[9] Miller, W. J., Econ. Geol., vol. XVII., pp. 709–713, 1922.

[10] Nason, F. L., Econ. Geol., vol. XVII., pp. 633–654, 1922.

[11] Newland, D. H., Econ. Geol., vol. XVIII., p. 291–296, 1923.

[12] Kemp, J. F., "The Geology of the Magnetites near Port Henry, N. Y., and especially those of Mineville," *Trans. Am. Inst. Min. Eng.*, vol. XXVII., pp. 146–204, 1898; *N. Y. State Mus. Bull.* 119, p. 57–88, 1908.

factory conception of the actual conditions, as I see them, than many of the more recent papers. Kemp sought a satisfactory explanation of the origin of these ore bodies when ideas regarding metamorphism of both igneous and sedimentary rocks were in their infancy. The rocks were all "gneisses." Having given the name "gneiss" to them it seemed to satisfy both the investigator and the reader, and so it did at that time. Kemp has very carefully described the country rock and skillfully pointed out, by the use of local names [13] the varieties and gradations to be found. By listing the minerals as revealed by the microscope for each "gneiss" the gradation from one extreme to the other is shown and supplements the field observations. One reading between the lines of this earlier paper, today may see that the gradation is from pure igneous rocks to undoubted sedimentary types. These intermediate rocks are syntectics of the geologist today. In his later paper, published in 1908, Kemp, because of the recognition of the syenite series in the Adirondacks by Cushing and the "basic" gabbros by himself, abandoned his local names and called the country rock of the magnetite bodies syenite. The ability to distinguish between the syenites on one hand and the Grenville series of sediments on the other truly marked an advance. But because the newer conceptions called for a separation between igneous and sedimentary rocks the *gradation* of the early paper is not so well emphasized.

From that time until Nason's papers [14] the majority of workers have assigned an igneous origin to them. In this group we note Kemp,[15] Newland,[16] Miller [17] and the writer.[18] Gradually the

[13] The "21 Gneiss," "Orchard Gneiss," "Barton Gneiss" and "Gabbro Gneiss." See *N. Y. State Mus. Bull.* 119 for Kemp's own correlation of these local names with the now recognized terms.

[14] F. L. Nason, ECON. GEOL., vol. XVII., pp. 633–654, 1922; XIX., pp. 288–295, 1924.

[15] Kemp, *N. Y. State Mus. Bull.* 119 and 138.

[16] D. H. Newland, *N. Y. State Mus. Bull.* 119; ECON. GEOL., XV., 177–180, 1920; XVIII., 291–296, 1923.

[17] W. J. Miller, ECON. GEOL., XIV., 509–535, 1919; *Bull. Geol. Soc. Am.*, XXXII., 63–64, 1921.

[18] J. F. Kemp and H. L. Alling, "Geology of the Ausable Quadrangle, N. Y.," *State Mus. Bull.* (in press 1924).

conception of magmatic assimilation crept into the accounts of these rocks. Miller has carried the idea to an extreme in that he calls upon included or assimilated material as the actual source of the iron itself.

In the early days geologists leaned strongly towards the belief that the country rock was sedimentary in origin. But the pendulum of opinion has swung to the igneous extreme; now it is swinging back again, and it will continue to oscillate between these until it is clearly recognized that the idea, contained in Kemp's early paper, of gradation of rocks composed of both igneous and sedimentary materials constitute the country rock of these magnetite deposits. In some cases the country rock is dominantly igneous, as it is on Lyon Mountain, Arnold and Palmer Hills; others are intermediate. Newland has well brought out the fact that a classification of the wall rock into either igneous or sedimentary types is, at certain localities, exceedingly difficult. He says:[19] "One may draw the line between typical Grenville and typical syenite, or granite, fairly easily. There is a goodly residuum of materials, however, that are not typically the one or the other, but if anything a blending of igneous magma and sediments due to the partial or complete assimilation of the latter in invading rock." This conception of sedimentary admixture in the igneous rocks, that is, rocks composed of both igneous and sedimentary matters, has been appreciated by all the geologists who have studied the magnetite deposits of the state. Kemp's[20] description of the 'Barton' Gneiss suggests that he had a suspicion in 1897 that the Grenville sediments had been incorporated into the rock. All later writers have amplified and extended this conception.[21]

Nason[22] furnishes diamond drill core records, which to me can best be explained by assimilation or magmatic replacement of Grenville rocks.

[19] Newland, D. H., Econ. Geol., vol. XVIII., p. 295, 1923.

[20] Kemp, J. F., *Trans. Am. Inst. Min. Eng.*, vol. XXVII., 1897, p. 34 of reprint.

[21] References to the literature are too extensive to be given. Smyth, Kemp, Cushing, Ogilvie, Miller, Martin, Buddington and I have expressed the idea. See *Am. Jour. Sci.*, (5) vol. VIII., pp. 12–32, 1924.

[22] Nason, F. L., *loc. cit.*, pp. 633–654.

Structure of the County Rock.—All observers agree that the bodies, variously described as pods, lenses, shoots, zones, or bands,[23] are roughly parallel to the foliation of the inclosing rock. Some have emphasized this more than others. Some say that the parallelism is perfect, others that it is only approximate. In explanation of the foliation there is a wide difference of opinion. The various theories are briefly discussed below and summarized in Table I.

The early geologists held that the foliation of the igneous rocks in the Adirondacks was due to severe metamorphism *after* they had crystallized. Thus the banded ortho-gneisses owed their structure to dynamic disturbances which affected the area after they had solidified.

Miller [24] on the other hand, believes that the foliation of the wall rock is due to magmatic flowage during crystallization of the granite. He denies any severe orogenic disturbance, (diastrophism) before or since. This view marks a complete departure from the older ideas. It is believed by the majority of the Adirondack geologists, that this seems too extreme to be acceptable. If some, *but not all,* of the foliation should be ascribed to flowage, many would be willing to agree with him. Miller's claim that the Grenville strata has never been severely folded or compressed has caused some to question his proposed theory of the origin of the foliation of the igneous rocks. Nevertheless I am inclined to the view that some foliation can be adequately explained by assuming magmatic flowage. But I am convinced that a large share of the foliation with which we are here concerned is due to other causes.

Colony,[25] following the work of Berkey in the Highlands of the Hudson, believes that the structure of the inclosing wall rock of the magnetites of Southeastern New York is an inherited one. He holds that the Grenville [26] has experienced profound meta-

[23] In a true sense no word expresses the real conditions. "Ore zone" is my preference.

[24] Miller, W. J., *Jour. Geol.*, vol. 24, 587–619, 1916.

[25] Colony, R. J., *N. Y. State Mus. Bull.* 249–250, 1923.

[26] There seems to be ample evidence that the old sediments in the Hudson Highlands can be correlated with the Grenville.

morphism, folding, faulting, and re-crystallization *before* the various intrusives entered. The structural planes, original bedding and secondary foliation, controlled the direction taken by the penetrating magmatic solutions; in soakings, saturations, and injections.

A similar origin for the foliation of the Adirondack rocks has recently been advocated: [27] that the foliation of the rocks situated beneath a sedimentary cover is a superimposed one. Colony used the term "inherited structure"; I used "superimposed foliation"; two ways of expressing the same idea.

Applying this conception to the magnetite belts the parallelism of the ore and the foliation of the inclosing syenite-granite-Grenville syntectic wall rock can be explained. The ore bodies, I believe, are in part at least replacements of the magma-saturated Grenville (and perhaps metagabbro) roof fragments and xenoliths. The presence of the replaced and perhaps assimilated Grenville has, in my opinion, a direct influence on the distribution and form of the ore bodies. This adequately accounts for the structure assumed by them, which Kemp has emphasized when he says: [28] "The ores do certainly imitate to a marked degree the folds and similar structures of stratified rocks. . . . If [the wall rock is] sedimentary, they must have been folded under such extreme pressure that the rocks flowed after the manner of viscous materials. . . . These folds are undoubtedly not essentially different from others well recognized in regions of metamorphosed, sedimentary rocks." I would point out that, according to my conception, "the ores . . . imitate . . . folds . . . of stratified rocks" because they are, in part, replacements of roof fragments of highly folded Grenville sediments. This dependence of the incorporated Grenville upon the form and structure of the magnetite deposits is my main contention.

Newland apparently questioned this in 1920 for he says [29] that "admixture [of the granite] with foreign material seems to have no bearing on the distribution of the ores in general." In

[27] Alling, H. L., *Am. Jour. Sci.*, (5) vol. XIII., pp. 12–32, 1924.
[28] Kemp, J. F., *N. Y. State Mus. Bull.* 138, p. 128, 1910.
[29] Newland, D. H., ECON. GEOL., vol XV., p. 179, 1920.

1923 [30] he says that the ore zones and the granites and gneisses are elongated in the same direction, " an inheritance perhaps of an early defined line of weakness marked out in the old Grenville." He has developed a conception, given below, so similar to the view here stated that it is interesting to note that he reached the same conclusion independently. He says: [31] " Much of this apparent foliation is really original pressure effects or magmatic flowage in conformity with the cooling surfaces, and not a secondary gneissic structure. In the case of sills that have penetrated along the bedding of Grenville schists, there results a conformable arrangement between the foliation of the granite or syenite and the schistosity or bedding of the sediments, which have had a directive influence upon the course of the magma. In other words the latter has molded itself to the former." Miller [32] disagrees with Newland's 1920 statement. I would be more willing to join with Miller in his disagreement if Newland had not given us his newer (and to me a very significant) conception, a statement which has appeared since Miller voiced his lack of belief.

If we compare the conceptions of the origin of the foliation of the country rock offered by Newland in 1923 and Miller in 1916 and again in 1919 we are impressed with many points in common. Newland calls upon magmatic flowage controlled by the presence of the foliated Grenville. Miller emphasizes flowage alone. Colony and I have been impressed by the inheritance from the Grenville. Apparently all are more or less in agreement, some stressing one factor, others still additional ones. Perhaps in our desire to present a simple conception we have over-emphasized one factor and ignored or neglected others. The truth may be that all the factors have been instrumental.

Nason, appreciating this parallelism of the foliation of the wall rock and the ore as a practical guide in the exploration for additional ore reserves, their conformity to the structural behavior

30 Newland, D. H., Econ. Geol., vol XVIII., p. 295, 1923.

31 Newland, D. H., Econ. Geol., vol. XVIII., p. 294, 1923.

32 Miller, W. J., Econ. Geol., vol. XVI., p. 230, 1921.

of the Grenville, and the distances along which the ore bodies [33] can be traced, suggests that the magnetite may be sedimentary. This is a very shrewd observation and cannot be criticized in any dictatorial way. His long experience with the magnetite deposits in New Jersey as well as in New York deserves the respect of all geologists.

My belief is that those who advocate an igneous origin, no matter what the actual processes may be, have not fully utilized Nason's observations. That is to say: (1) The *structure* of the wall rock is of *sedimentary* origin, (2) The composition of certain bands in the wall rock is sedimentary, (3) But the ore is, I believe, of igneous origin.

TABLE I.

THEORIES OF THE FOLIATION OF THE COUNTRY ROCKS OF THE MAGNETITE DEPOSITS.

1	2	3	4	5
Kemp, Newland,* Cushing, Ogilvie.	Miller.	Colony.	Nason.	Alling.
Secondary, due to regional metamorphism after igneous injection.	Primary, due to magnetic flowage during crystallization.	Inherited structure derived from structure of Grenville.	Primary, due, in part, to original sedimentation.	Chiefly superimposed from Grenville and to minor degree to magmatic flowage.

* Newland in 1923, "Magmatic Flowage along Schistosity of Grenville Sediments."

Pegmatites.—There is general agreement that the magnetite and the wall rocks are seamed and intricately cut by numerous pegmatites, veindikes, silexite dikes, and quartz veins. They are of various compositions and ages. Kemp calls particular attention to the beautifully crystallized minerals found in them. Palmer Hill is, as Newland has pointed out, noted for its fluorite

33 The ore bodies themselves are not continuous over any great distance. The lenses, pods or zones lie at various depths and often overlap, pinch, and swell, and locally are strung together by zones of lean ore. The greatest distance that ore zones are known to extend is about thirteen miles.

granite. Tourmaline, allanite, zircon and other pegmatitic minerals have been listed and described.[34]

Kemp stated that the pegmatites were associated with the origin of the magnetite. He says:[35] " . . . Streaks of pegmatite run parallel with the general foliation and . . . give the impression of having been intimately involved with the ore at the time of formation. . . . They are strongly suggestive of . . . the expiring stages of some intrusive mass. . . . If . . . we connect them with the ore, they must mark an attendant phase of its separation." Miller has emphasized pegmatites as the transporting and concentrating agents of the magnetite.

Kemp states that there are some coarse grained hornblendic[36] pegmatites containing "coarse crystalline magnetite." Miller has found on Lyon Mountain "what appear to be true dikes of practically pure magnetite."[37] His observation collaborates Kemp's early statements. Magnetite in quartz veindikes occurs on Palmer and Arnold Hills.[38] The advocate of magma derived ores has no difficulty in believing that the veindikes represent late stage or deuteric development of the intrusive, and is not disturbed by a difference in the composition of this late stage-magnetite from the previously deposited magnetite that constitutes the ore bodies. Nason, because of difference in experience and training, is "inclined to be skeptical as to a common origin . . . The dike ore is certainly secondary to its rock host."[39] What is proof to one may not satisfy another.

[34] See Whitlock, H. P., *N. Y. State Mus. Bull.* 107, pp. 55–96, 1907; Ries, H., *N. Y. Acad. Sci. Trans.*, 1898, vol. 16, p. 327–29; Dana, E. S., *Am. Jour. Sci.*, 1884, p. 479.

[35] Kemp, J. F., *N. Y. State Mus. Bull.* 138, p. 125–6, 1910.

[36] It may be that in the majority of cases they are really pyroxenic rocks.

[37] Nason, F. L., Econ. Geol., vol. XIX., p. 292, 1924, would prefer to call them "pegmatites." Spurr would call them "veindikes." Miller uses the term "practically pure magnetite," which Nason, naturally interprets to mean a possible mill ore. Analysis shows 6.66 per cent. Ti. This is not a commercial ore. Miller wishes to convey the impression that the veindike was chiefly composed of quartz and magnetite. The latter turned out to be titaniferous.

[38] Polished pieces show that this magnetite is martitic. It is believed that martite can dissolve a titanium compound.

[39] Nason, F. L., Econ. Geol., vol. XIX., p. 292, 1924.

Continued study of the Palmer and Arnold Hill mines has revealed that there are two contrasted types of pegmatites. One is decidedly acid; composed of quartz and potash rich feldspar,[40] frequently with magnetite. The other type is more basic; containing quartz, microperthite, oligoclase and either pyroxene or hornblende together with magnetite. Each type is cut by the other, indicating simultaneous development of the two kinds. They frequently follow the general foliation of the wall rock, as Kemp noted long ago. It is believed that this gives a clue to the mode of differentiation of the magma, which is considered the source of the magnetite. It indicates, I believe, that two contrasted differentiates separated. Colony,[41] in describing the magnetites of southeastern New York states that after the first differentiated portion had been formed "subdifferentiation of the concentrate itself [took place], into pegmatite-rich and magnetite-rich fractions." I am inclined to accept this view and apply it to the Adirondacks.

"Foreign" Rocks in the Wall Rock.—As has been stated above, the wall rock is believed to be a syntectic, that is, composed of an igneous rock, a member or phase of the syenite-granite series, and assimilated or replaced older rocks. It is also believed that the bulk of the absorbed rock is Grenville. Cook Hill rocks contain considerable biotite,[42] which is considered to indicate absorbed Grenville. A few cores of unassimilated xenoliths have been found on Arnold Hill. Slides cut from rock-dump material on Palmer Hill suggest the same thing. Some of the absorbed material can with certainty be identified as Grenville. Much of it, however, cannot positively be ascribed to that series. The finding of basic rocks throughout the Adirondacks which can be called "metagabbros" strengthens the belief that the wall rocks have absorbed and digested metagabbro masses as well

[40] This expression covers orthoclase, microcline, soda orthoclase, soda microcline and hypoperthite. Frequently the feldspar contains flakes of hematite furnishing a pink or reddish color to the mineral.

[41] Colony, R. J., *loc. cit.*, p. 70, 1923.

[42] Newland, D. H., *N. Y. State Mus. Bull.*, 119, p. 103, 1908.

(see Fig. 1, *H*). This is in perfect agreement with Miller's conclusions.

The variable composition of the Grenville series and the degree to which individual beds have been incorporated produces a profusion of different aspects. It is thus possible that a great many mineral combinations can be found in the wall rocks.

NOMENCLATURE.

Great difficulty is experienced in synthesizing the literature because of lack of uniformity in the use of words. This is to be expected. Nason does not use the same terms as Kemp, Newland, or Miller. He referred to the "gabbro" at Ausable Forks. In all probability he means the dark green augite syenite. The nature of the feldspar is not easily determined by the hand specimen alone. "Basic syenite" might be substituted for some of Nason's "gabbro" but not all of it. Nason suggests that his gray gneiss, the wall rock of the ore bodies, may be a derivitive of "gabbro." He probably means "basic syenite." Nason has confused "black rock," amphibolite, basic syenite and syenite-granite-Grenville syntectic. What his "black rock" is I don't know. It may be a number of things. Nason[43] says: "the 'black rock' of the writer [Nason] may be the 'amphibolite' of Kemp and Newland and this, in turn, according to these authorities, is a dark pyroxene phase of the typical green syenites." This complicates matters. True amphibolites, as the names indicate, are amphibole bearing rocks, not pyroxene rocks. From my acquaintance with Professor Kemp and Mr. Newland and their papers, I should judge that Nason has incorrectly correlated his "black rock." His statement means very little.

Another of Nason's statements that is difficult to understand is that if the "black rock" is the amphibolite of Kemp and Newland, "the gray gneiss cannot be a metamorphic phase of the syenite, since a phase of the syenite is intrusive in the gray gneiss." [44] If the gray gneiss is a syenite-granite-Grenville syn-

[43] Nason, F. L., Econ. Geol., vol. XVII., p. 643, 1922.

[44] Nason, F. L., *Idem*, p. 641.

tectic, why cannot a slightly later phase of the syenite series, a granite, cut it without throwing the gray gneiss out of the syenite category? The syenite has been observed in numerous places cut by itself, although I have never seen it in the neighborhood of the mines. The pegmatites are believed to have been derived from the syenite magma and yet they cut the syenite. Consequently I feel very confident that Nason is not justified in criticising Kemp and Newland in mapping the "nontitaniferous magnetites" in the syenite-granite series.

He further says: "if the gray gneisses are intrusive, they must be older than the syenites. That the gray gneisses are older than the gabbros and anorthosites there is no possible question." This is a puzzling statement. If the gray gneiss is a syntectic, as I hold, the remark that "if they are intrusives" refers, I take it, to the igneous phase of the rock and not to the sedimentary phase (to use Nason's own expression), then Nason is overstressing the fact that a "phase of the syenite" cuts it. This is a matter of personal opinion. But to say a phase of the (igneous) syenite series is older than the anorthosites is probably incorrect. If, however, Nason is referring to the Grenville portion of the gray gneiss syntectic, I will readily agree. What is Nason's "gabbro"? Is it the post syenite-granite gabbro, first recognized in the Adirondacks by Kemp? or a metagabbro? There are certainly gabbros in the Adirondacks older than the syenite series.

In view of the great difficulty with the nomenclature I have attempted to correlate the various terms used by the above writers with the results shown in Table II.

CONTACT ROCKS.

Palmer and Arnold Hills have furnished specimens that can be interpreted only as contact zone rocks; rocks produced by the chemical activity of igneous matters from an underlying magma upon sedimentary materials. Such rocks contain garnet, scapolite, titanite, diopsidic pyroxene and calcite. One specimen is an intergrowth of garnet and magnetite. The latter mineral is coated and veined with martite (see Fig. 1, *G*). It is suggested

TABLE II.

CORRELATION OF THE ADIRONDACK ROCKS.[45]

1	2	3	4	5
Kemp, 1897–8.	Newland & Kemp, 1908–10.	Miller, 1919.	Nason, 1922.	Alling, 1924.
"21" Gneiss - - - -?- - - -	Syenite Series	Lyon Mtn. Gran.	Gray Gneiss	Ore-formation granite
		Hawkeye Gran.	Syenite* (green)	Soda Granite
				Syenite-Granite (Quartz Normarkite)
		Syenite	Basic Syenite* (Ti free)	Syenite. (Normarkite)
Orchard Gneiss	Hammondville	Diorite		Quartz Diorite
Barton Gneiss	Syenite-Granite Grenville mixtures	Syenite-Granite-Grenville Mixed Gneisses		Syenite-Granite-Grenville syntectic
Basic Gabbro	Basic Gabbro	Gabbro	Basic Syenite (titaniferous) some "gabbro"	(Algoman) gabbro
Gabbro Gneiss	Hornblende Gn and Amphibolites	Metagabbro	"Black Rock" in part. Metamorphosed Gabbro	(Laurentian) Metagabbro
		Hornblende Gn and Amphibolite		Grenville Paramphibolite
		Not recognized. (metagabbro)		(Keewatin?) Ortho-amphibolite

* Much of Nason's "gabbro" is unquestionably syenite and should be placed here.

that some contact action ("contact metamorphism") has taken place upon the Grenville and metagabbro that has been incorporated into the syenite-granite. How extensive or important this activity was is not known and consequently it is uncertain how

[45] This is not a complete correlation of *all* of the Adirondack Rocks. Here are given only those which are regarded as involved with the origin and geology of the magnetite deposits.

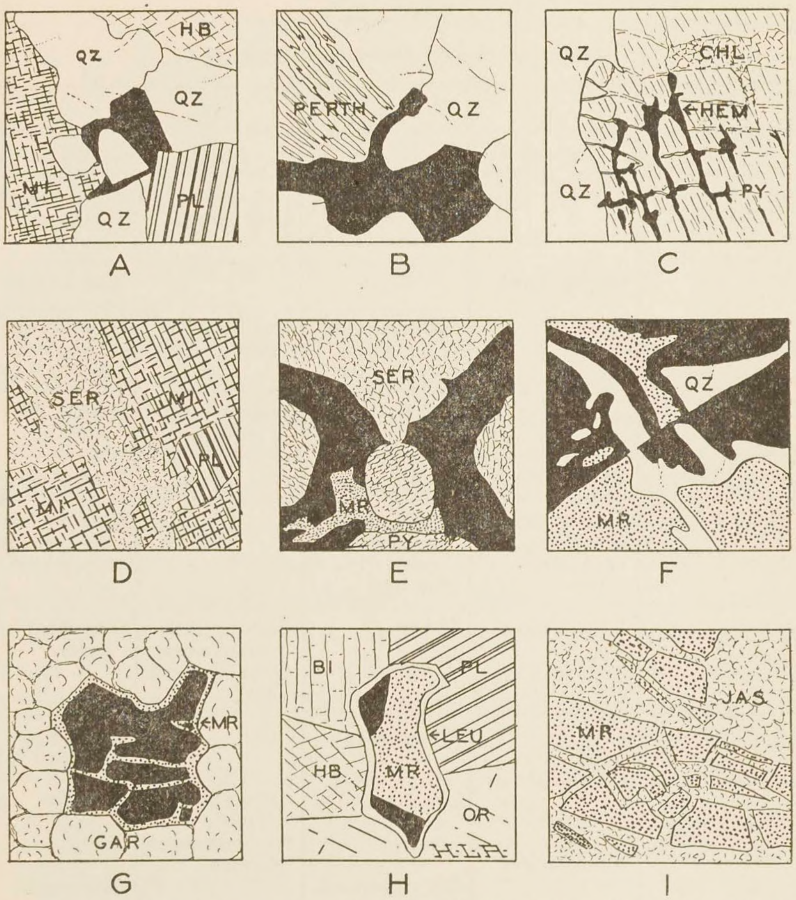

FIG. 1. *General Legend: QZ,* Quartz. *MI,* Microcline. *PL,* Plagioclase. *PERTH,* Perthite. *CHL,* Chlorite. *HEM,* Hematite. *PY,* Pyroxene. *SER,* Sericite. *MR,* Martite. *GAR,* Garnet. *BI,* Biotite. *HB,* Hornblende. *LEU,* Leucoxene. *OR,* Orthoclase. *JAS,* Jasper. *Black,* Magnetite (except in *C*). Magnification $\times$ 16.

A. Ore-formation granite, Cook Hill Mines (1094*b*) showing late magnetite.

B. Ore-formation granite, Cook Hill Mines (1092*b*) showing late magnetite.

C. Soda-rich pyroxene in Ore-formation granite altering to hematite and chlorite. Palmer Hill (351).

D. Microcline and plagioclase in ore-formation granite altered to sericite by aqueo-igneous solutions. Palmer Hill (353*a*).

much emphasis it should receive as a factor in the ore-formation process. That it was a factor, however, there is no uncertainty. Although Kemp in 1897 referred to the ore as " contact replacement deposits " it is not clear whether the two statements amount to the same thing or not.

MARTITE

Newland has noted the ferric oxide mineral, martite, as a notable constituent of the ore on Arnold Hill. In thin section, and illuminated by a Silverman lamp [46] it appears bluish black, while magnetite under the same conditions is steel gray. Martite is decidedly less magnetic than magnetite. Apgar [47] found that experimental " magnetic separations on small crushed samples were in some cases giving anomolous results at variance with the microscopic identification, . . . certain ores determined to be almost wholly martite showed magnetic qualities. . . . For this reason a special method of investigation was devised, the polished surface of the sample was scratched or abraded with a fine pointed diamond under the microscope. The appearance of the abrasion surface, the color of the fragments or powder produced by

46 Manufactured by Ludwig Hommel & Co., Pittsburgh, Pa. It consists of an annular lamp of daylight glass encircling the objective, furnishing a cone of oblique light which is reflected up the tube of the microscope.

47 Apgar, Fred. W., " Petrographic Report on Suite of Rock and Ore Specimens from Lake Champlain District and Vicinity," p. 95–96, Nov. 23, 1914. A copy now in my library. Acknowledgment is gratefully made to Mr. Apgar for permission to quote from this report.

E. Late magnetite partially replaced by martite in ore-formation granite. Arnold Hill mines (1468).

F. Martite replacing microfaulted magnetite in veindike. Palmer Hill mines (351).

G. Magnetite, coated and veined by martite, in garnet contact rock. Palmer Hill mines (353*B*).

H. Introduced magnetite, replaced in part by martite, in metagabbro xenolith. Arnold Hill mines (1091*C*). Note that the magnetite that has replaced biotite has not been replaced by martite.

I. Brecciated martitic ore, cemented by Jasper. Arnold Hill mines (*A*-410).

scratching, and the magnetic qualities of the powder when tested with a magnetized needle were rather distinctive. . . . Magnetite in all cases showed a dark steel gray abrasion surface, dull black powder or 'streak' and strong magnetic qualities in the loosened fragments. . . . With martite the scratch powder or fragments, in some of the samples, proved to be non-magnetic, the abrasion surface being steel blue in color and the powder or 'streak' dark red; this material was hard and compact, the other samples gave a variably magnetic powder, had somewhat lighter 'streak' and abrasion surface and the mineral showed less coherence, being softer and more brittle.

"It is believed that the magnetic qualities of some of this red powder are due to finely disseminated . . . magnetite particles in the martite . . . and while this aggregate nature of the martite could not be confirmed by microscopic observation owing to the difficulty of obtaining a good plane surface polish still there would seem no question but that such is the case, in those samples giving non-magnetic scratch powder the [mineral is regarded as pure martite without magnetite admixture]."

On Arnold Hill there are ore-bodies that consist chiefly of martite, the magnetite content being relatively small. One ore-body was called the "blue vein" because it was dominantly martite,[48] while other bodies close by are composed of magnetite

TABLE III.

RECAST OF ANALYSES OF ORES FROM THE ARNOLD-COOK HILL DISTRICT.

	1	2	3
Martite	69.55	.238	0.00
Magnetite	17.00	87.250	83.89
Ilmenite	.46	.779	.93
Apatite		.123	.11
Pyrite		.065	.07
Chalcopyrite	.011		
Pentlandite	.009		
Gangue	12.77	11.545	14.44
	99.800	100.000	99.44

1. "Blue Vein," Arnold Hill. Mr. S. Le Fevre.

2 and 3. Cook-Hill Ore. James Brakes.

48 See Newland, D. H., *N. Y. State Mus. Bull.* 119, p. 98, 1908.

with little or no martite. Field studies fail to reveal an entirely satisfactory reason for this difference. A common, though not invariable, association is microfaulting and brecciation. Microscopic studies have shown martitic ores without brecciation. But brecciated ores in all the cases examined, are martitic. The inference is therefore reached that brecciation and microfaulting are functions of the formation or deposition of the martite.

The mode of formation of the martite is not evident in the extremely rich martitic bodies. The martite is associated with quartz, soda-rich feldspars, augite, hornblende, and the alteration products of these gangue minerals. Much of the martite lies in enbayments in, and holds inclusions of, quartz. It certainly is not an early deposited mineral.

Better results are forthcoming from specimens that show both magnetite and martite. Here the martite is coating and veining the magnetite. Replacement of the magnetite by the martite has taken place (see Fig. 1). It is commonly assumed that the change of magnetite to martite is due to oxidation of the magnetite. This view is undoubtedly based upon the similarity of the two formulas: Fe_3O_4 and Fe_2O_3. Especially if the formula for magnetite is written $FeO \cdot Fe_2O_3$.[49] Thus $2FeO \cdot 2Fe_2O_3 + O = 3Fe_2O_3$ is suggestive of oxidation. But magnetite is not a mixture of ferrous and ferric iron; it is spinel—ferrous ferrate. Crystallographically they are distinct.

The advocates of the oxidation theory have difficulty in finding the source of the oxygen. Some have regarded the change as secondary, having taken place near the surface, following long erosion.

Newland [50] has recently suggested that the martite was derived from the basaltic (diabasic) dikes that cut all the other Precambrian rocks. He sought a basic intrusive as the most likely rock to have furnished it. I believe that Newland's suggestion is probably incorrect as I have found no real relation between the

[49] This form is necessary when a chemical analysis is recast but I believe that an erroneous idea is obtained if it is retained as indicating the chemical nature of magnetite.

[50] Newland, D. H., Econ. Geol., vol. XVII., pp. 299–302, 1922.

dikes and the ore bodies rich in martite. Furthermore, on Palmer Hill a dike has penetrated a fault breccia. This breccia consists of fragments of pegmatitic veins (veindikes) of quartz, microcline and magnetite. The magnetite is in part replaced by martite. Hence a period of faulting must have taken place after the martite replaced the magnetite and before the intrusion of the dike. It is true that even the basaltic dikes are not all of the same age, yet they are all known to be later than the syenite-granite intrusives. Even though definite information about martite as such is scanty, I conclude that the oxidation theory is unnecessary and inadequate. The deposition of the martite points to deep seated conditions rather than to surface oxidation. The view here taken is that the martite is a late magmatic introduced mineral which replaced the previously deposited magnetite. The martite is considered to have been derived from a basic differentiate of the syenite-granite magma.

THE SEQUENCE OF ORE DEPOSITION.

Petrographic studies of the wall rock reveal that the magnetite is not of single age. Hundreds of feet away from the ore bodies the magnetite appears to have crystallized at an early stage; following the usual order announced by Rosenbusch. So fixed has this order become in the minds of some that no departure from it is recognized. A departure, however, does occur. Specimens collected close to the ore bodies contain, in addition to the early crystallized magnetite, other grains of the same mineral that occupy interstitial position[51] (see Fig. 1, *A, B*). As the ore bodies are reached the later crystallized magnetite is in abundance and in the ore proper constitutes the bulk of the rock.

This later magnetite, for reasons still unknown, was more susceptible to replacement by martite than the early magnetite (see Fig. 1). Newland recognized both types. In addition to the early and late magnetite there is veindike or igneous-hydrothermal magnetite[52] which cuts the wall rock and the ore bodies. Thus

[51] A great increase in the amount of one component in a multicomponent system often reverses the order of separation during freezing.

[52] Recall Miller's "true dikes of practically pure magnetite."

there is magnetite of three distinct ages. Kemp regards the magnetite as early, Colony and Miller have emphasized the late magnetite. In the Palmer, Arnold, Cook and Jackson Hill mines all three types are observed by means of petrographic examination. All three ages are replaced by martite, the late and vein-dike magnetite especially.

Following the martite ferrugenous vein quartz was introduced, cementing the breccia of martitic bodies on Arnold and Palmer Hills. Calcite veining seems to have been the end phase product. All are regarded as of magmatic origin. The chief factor controlling this sequence was the falling temperature of the magma (see Fig. 1).

The nature of the later magnetite as seen under the microscope indicates that some of it has replaced the usual minerals of the granitic wall rock; especially quartz and the feldspars. There is some indication that some of the pyroxene has suffered decomposition with a separation of hematite, not martite, which in turn has been replaced, rimmed and veined by introduced magnetite and later by martite (see Fig. 1, *C*). It is quite possible that corrosive solutions, derived from the differentiating magma, brought about this alteration of the pyroxene.

This replacement may have been brought about by at least two processes: (1) That the later magnetite was introduced by aqueo-igneous solutions (end phase or deuteric processes) and replaced the quartz and the feldspars. If so, it may be that previous sericitization of the feldspars by corrosive magmatic gases and liquids made the feldspars more susceptible to replacement. (2) That the presence of large quantities of potential magnetite in the iron rich subdifferentiated magma reversed the sequence of crystallization. During the late stages of crystallization reaction took place between previously formed crystals and the remaining liquid, corroding the feldspars and the quartz. The magnetite crystallized in the interstitial spaces.

There is really little choice between these suggested processes. They are very similar, differing chiefly in the *time* of the formation of the magnetite.

Source of the Iron.—Those advocating an igneous origin of the magnetite deposits can be grouped into two classes. (1) Those who hold the source to be the wall rock, that is, the syenite-granite, and (2) Miller who proposed that assimilation of basic rocks, Grenville paramphibolite and metagabbro with a change of hornblende and hypersthene into diallage, furnished the iron.

DISCUSSION OF MILLER'S THEORY.

Palmer Hill exhibits a remarkably clean igneous rock. There is some evidence that some Grenville sediments have been replaced or perhaps assimilated. How much there has been absorbed is, of course, unknown. It is extremely difficult or impossible to obtain quantitative data; nevertheless the amount of material absorbed is regarded as small and insufficient to account for the magnetite actually known to have been formed. It is true that other mines show more assimilated foreign rock than Palmer Hill, sufficient perhaps to have furnished the iron. But on Palmer Hill I hold the theory is inadequate. It is concluded therefore that (1) magmatic replacement, assimilation and digestion of amphibolite (and metagabbro), and (2) the source of the magnetite are independent and not dependent. If the titaniferous magnetites be called magmatic, as is often the case, I feel that the Palmer Hill ores must be included in this class also since I believe they are differentiates of a granitic magma. I prefer a consistent theory of origin for all the Adirondack magnetites.

Studies by Bowen [53] indicate that magmas lack sufficient heat to digest great quantities of foreign rock.

I have a growing tendency to distinguish between magmatic assimilation, an actual melting in, of roof fragments and xenoliths on one hand and magmatic replacement of such foreign bodies by aqueo-igneous solutions derived from a differentiating magma on the other. Bowen urges caution in postulating wholesale assimilation by thermal action. If, however, chemical activity, reaction between solid crystals and the liquids of the magma is possible, replacement of roof fragments may take place. This

[53] Bowen, N. L., *Jour. Geol. Suppl.*, No. 6, pp. 513–570, 1922.

would remove the objection that the magma does not possess sufficient heat (calories) to fuse pieces of the country rock. The conception I am developing is apparently a departure from Daly's rather violent stoping to a more gradual infiltration, soaking and penetration of highly foliated rock cover and by chemical, as opposed to thermal, reaction replacing the country rock by igneous minerals. Whether material from the old invaded rock can or does unite with igneous contributions, in a simular way to the production of garnetiferous contact zone rocks, is still, in my mind, an unsolved problem. This conception of slow magmatic replacement, I think, would require but a small quantity of foliated country rock to impress its structure upon the resulting syntectic; an amount too small to have furnished the iron for the magnetite ore bodies. I feel that more study in the laboratory should be forthcoming before we present a definite solution to this problem.

Newland [54] feels that Miller's theory " fails to account for the iron content of the granite in its normal phases." In reply Miller [55] says: " The normal granite is that which is free from contamination or close association with old gneiss. Examination of many thin sections of such normal granite of the *Lyon Mountain* and *other areas* [56] shows that it is very ordinary as regards iron content, the magnetite rarely running over a few per cent., while ferro-magnesian minerals run very low." Apparently Newland and Miller differ as to the facts. But I should judge that they have had a different experience. Newland [57] says of the red granite, (the ore-formation granite of my nomenclature) two miles east of Ausable Forks: " The rock is an interesting type, as it belongs to the true granites, being composed of feldspar and quartz in normal propositions, but on the other hand

54 Newland, D. H., ECON. GEOL., vol. XV., p. 180, 1920.

55 Miller, W. J., ECON. GEOL., vol. XVI., p. 232, 1921.

56 The italics are mine.

57 Newland, D. H., " The Quarry Materials of New York—Granite, Gneiss, Trap and Marble," *N. Y. State Mus. Bull.* 181, 1916, p. 98, a bulletin available to Miller when he differed from Newland in regard to the magnetite content of the normal granite.

contains no dark silicates of the mica, amphibole or pyroxene families. In place of such minerals, however, it carries a large amount of magnetite which ordinarily is a very minor constituent of granite. This mineral constitutes about 15 per cent. of the entire rock." Miller's slides were prepared from Lyon Mountain and other areas. My slides of Lyon Mountain country rock show a low magnetite content. The same is true of specimens from Port Henry, Mineville and Hammondville. But on Palmer and Arnold Hills the magnetite content is abnormally high. On the Palmer Hill, as maintained above, the Grenville and metagabbro incorporated in the ore-formation granite is considered to be small in amount. Differentiation instead of assimilation is regarded as a more satisfactory explanation of the high magnetite content. I feel confident that Palmer Hill is an exceedingly significant locality in that it presents a more simple geology. Its study throws some question upon the adequacy of Miller's theory to account for the magnetite bodies.

THE ORE-FORMATION PROCESSES.

Having decided that a magnetite rich granitic differentiate of the syenite-granite intrusives was the primal source of the ore bodies, the problem remains; how did these bodies come into existence? The early workers, perhaps quite naturally, were content by stating that the ore was due to magmatic differentiation. This is, today, only a partial answer to our inquiry. I see the same picture, that Colony so vividly paints, of continued differentiation, or to use his words, subdifferentiation of this differentiate into pegmatite-rich and magnetite-rich portions. These two fluid and chemically active aqueo-igneous solutions under pressure (Spurr's "telluric pressure") concentrated the magnetite in lens shaped bodies by replacing previously foliated inclusions and roof fragments of Grenville or metagabbro and portions of the already solidified granitic country rock. Still later and consequently cooler, pegmatitic, silexitic, veindikes of magnetite-rich silicious solutions cut and veined the ore bodies. Microfaulting, following cooling, brecciated the ore locally, permit-

ting a late stage magmatic solution carrying potential martite to infilter. The shattered magnetite was replaced in whole or in part by martite in certain zones. The last and dying igneous activity was the veining of the brecciated ores by ferrugenous quartz and finally by calcite.

Thus the pegmatitic solutions were, under this conception, powerful agents in the transference and concentration of the ore. Kemp caught some of the significance of the pegmatites in the ore formation processes, but did not appreciate their importance. Newland [58] emphasized the pegmatites when he says "magmatic differentiation has been . . . a prominent factor in the *early* [59] stages of their formation. . . . Yet there is reason for believing that *other* [59] agencies were active in producing the final results. Of these the influence of highly heated vapors and waters . . . has been most important. . . . This agency would be especially active in the *final* [59] stages. . . . In some cases it may have been the determinative factor in bringing the iron minerals into their *present* [59] position."

Miller has stressed pegmatites more than the others. Bayley [60] also calls upon them as important agents in the formation of the magnetite deposits in New Jersey and in North Carolina. Colony's important paper [61] on the magnetites of Southeastern New York stresses the aqueo-igneous solutions and the replacement of the Grenville sediments incorporated in the granite. The ore-formation processes, Colony holds, and I agree with him, were subjected to the structural control of the previously foliated Grenville.

SUMMARY.

The chief purpose of this paper is to summarize the recent literature dealing with the Adirondack non-titaniferous magnetites, to state as clearly as possible the various theories offered

58 Newland, D. H., *N. Y. State Mus. Bull.* 119, pp. 31–32, 1908.

59 The italics are mine.

60 Bayley, W. S., "The Magnetite Ores of North Carolina—Their Origin," Econ. Geol., vol. XVI., pp. 142–152, 1921.

61 Colony, R. J., *loc. cit.*, p. 70.

TABLE IV.

TABULATION OF THE RECENT THEORIES PROPOSED TO EXPLAIN THE ORIGIN OF THE ADIRONDACK NON-TITANIFEROUS MAGNETITE IRON ORE DEPOSITS.

	1 Kemp, 1897–8.	2 Newland, 1908.	3 Kemp, 1908.	4 Kemp, 1910.	5 Miller, 1919.	6 Nason, 1922.	7 Colony, 1923.	8 Alling, 1924.
District	Port Henry-Mineville	Adirondacks	Port Henry-Mineville	Port Henry-Mineville	Lyon mts. etc.	Port Henry-Mineville	Southeastern New York	Chiefly Palmer-Arnold Hill
Nature of wall rock	Perhaps igneous Perhaps sedimentary	Igneous	Igneous	Igneous	Igneous	In part Sed.	Igneous and sed.	Igneous and sed. syntectic
Wall rocks	"21" Gneiss Orchard Gneiss Barton Gneiss	Syenite Ser. Granites Syenites Diorites	Syenite Ser. with local inclusions of Grenville	Syenite Series { "21" Gn. Orchard Barton Basic Sye. Igneous-Grenv'	Lyon Mtn. Granite. Hawkeye Granite Sye.-Granite metagabbro Sye.-Gran. mixed rocks	"Grey Gneiss" Part of Grenville Series	Pochuk (Igneous) Grenville (Sediment)	Ore-formation granite-(Syenite-granite ser.) Grenville syntectic
Associated rocks	Gabbro Gneiss Pegmatites	Hornblende Gn. Grenville Ser. Pegmatite	Hornblende Gn. Basic Gabbro Grenville Ser. Pegmatites	Hornblende Gn. Basic Gabbro Grenville Ser. Pegmatites	Hornblende Gn. Metagabbro Amphibolite Pegmatites	Green Syenite Basic Syenite "Black Rock" Gabbro, Grenv.	Diorites Syenites Grenville Pegmatites	Diorites Syenites Amphibolites Grenville. Peg.
Source of magnetite	"21" Gneiss Orchard Gn.	Syenite Ser.	Syenite Ser.	Syenite Ser.	Inc. of Grenv. amphibolite and metagabbro Locally Syenite-Granite series		Pochuck Gn.	Ore-formation Gran. A differentiate of Syenite-Granite magma
Form and structure of ore bodies	Series of long pods	Pods, lenses and shoots. Conform to foliation of Wall Rk.	Imitate folds of Sed. Rocks. Belts parallel to foliation	Imitate folds Sed. Rocks. Belts parallel to foliation	Ore zones parallel to foliation of wall rock	Ore bodies conform to foliation of Grey Gn. and Grenville	Structure of ore bodies dependent on pre-existing structure of Grenv.	Ore zones roughly parallel to foliation of wall rock
Nature of the foliation	Dynamical, shearing and viscous flow	1908 Secondary 1923 Magmatic flowage along schistosity of Grenville sed.	Secondary Rocks folded since deposition of ore	Secondary Rocks folded since deposition of ore	Primary, due to magmatic flowage	Primary, due in part, to original sedimentation	Inherited from structure of previously folded Grenv.	Superimposed foliation from Grenville and to minor degree to flowage

	1 Kemp, 1897–8.	2 Newland, 1908.	3 Kemp, 1908.	4 Kemp, 1910.	5 Miller, 1919.	6 Nason, 1922.	7 Colony, 1923.	8 Alling, 1924.
Differentiation	Not suggested	Strongly emphasized	Implied*	Basic segregations due to differentiat.	Probably differentiat. took place locally		Differentiat. of basic magma rich in pegmatites; rich in magnetite	Differentiat. of ore-formation granite Pegmatite-rich Magnetite-rich fractions
Process emphasized	Contact action	Differentiat.	*	Differentiat.	Assimilation of inclusions of Amphibolite Hornblende Gn. (and) (or) metagabbro	Sedimentation Metamorphism	Subdifferentiation into (*a*) pegmatite rich, (*b*) magnetite-rich aqueo-igneous solutions	Subdifferentiation into (*a*) pegmatite rich, (*b*) magnetite-rich aqueo-igneous solutions
Transported by	Pegmatites	In part by Pegmatites	*	Pressure	Pegmatites		Aqueo-igneous solutions	Aqueo-igneous solutions
Other processes involved	Replacement of wall rock	Pegmatitic activity during final stages	*	Pegmatites associated with origin	Change of Hornblende and Hypersthene to diallage		Replacement of calcareous phases of Grenv. portions of Pochuck Gn.	Replacement of Grenville, part of syntectic, and wall rock
Time of crystallization of the magnetite		Early and late	*	Early	Early and late		Late	Early, late and end-phase
Type of deposits	Contact replacement deposits, due to highly heated igneous solutions	Deposits due to differentiation in early stages; and to pegmatitic activity in final stages.	Igneous*	Basic segregations due to differentiation	Igneous ore by pegmatitic deposition from basic inclusions. Locally from differentiation	Possibly metamorphosed sedimentary deposits	Magmatic-replacement deposits, *i.e.*, replacement deposits of deuteric origin	Magmatic-replacement deposits due to aqueo-igneous solutions from a differentiating granitic magma

* Kemp and Newland were co-authors of *N. Y. State Mus. Bull.* 119, 1908. Newland wrote most of it, including the subject of origin. Kemp treated the Mineville-Port Henry district, but did not discuss the genesis of the magnetite deposits.

to account for them, and to show that the ore-formation processes extended over an appreciable time and were of some complexity, perhaps more so than has heretofore been suggested.

The summary of the various theories is given in Table IV.

A summary of the ore-formation processes as I see them at the present time is as follows:

1. Magnetite-rich differentiate of the syenite-granite series.
2. Encountered the overlying and highly foliated Grenville (and metagabbro) rocks, penetrated and soaked along the foliation planes, gradually saturated and replaced these ancient rocks, took on the structure possessed by them and became a syntectic.
3. Subdifferentiation of still liquid portions of the magma into
   a. pegmatite-rich and
   b. magnetite-rich fractions.
4. This subdifferentiation may have been stimulated by the presence of these foreign rocks;
   a. through assimilation.
   b. affects of chill.
   c. catalytic action.
5. Slight contact action took place between the differentiating magma and roof fragments of calcareous Grenville, or upon solidified portions of itself, producing local concentrations of magnetite.
6. The magnetite-rich aqueo-igneous solutions saturated and replaced the syntectic wall rock subject to the structural control of the superimposed foliation of the country rock, producing local concentrations of magnetite.
7. The pegmatite-rich fractions, by transference, concentrated the magnetite into the zones where they are found today.
8. Still later aqueo-igneous magnetite-rich solutions veined the wall rock and the ore bodies.
9. Faulting upon a minute scale brecciated the ore in certain zones.
10. Relatively basic pegmatitic activity attacked the previously

formed and brecciated magnetite causing partial replacement by martite.

11. Renewed or continued acid pegmatitic and silexitic activity without much effect upon the ores.
12. Magnetitic and martitic replacement repeated through periodic and oscillatory operations of these processes.
13. Slight and local disturbances resulting in microfaulting and brecciation.
14. Introduction of veinlets of jasper.
15. Introduction of ferrugenous calcite.

Thus the non-titaniferous magnetite deposits of the Adirondacks are regarded as magmatic-replacement deposits due to aqueo-igneous magnetite-rich solutions derived from a differentiating granitic magma.

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